PRINCIPAL COMPONENT ANALYSIS OF ASTEROID SPECTRA USING ECAS AND 52-COLOR DATA. Thomas H. Burbine (Dept. of Geology and Planetary Science, Univ. of Pittsburgh, Pittsburgh, PA 15260) and Jeffrey F. Bell (Planetary Geosciences Div., Dept. of Geology & Geophysics, SOEST, Univ. of Hawaii, Honolulu, HI 96822)

Principal component analysis (PCA) has been shown to be a very useful technique for displaying multivariate asteroid spectra as shown by PCA's use in Tholen's asteroid classification system [1]. PCA transforms each asteroid spectrum into a new set of uncorrelated variables called principal components. These new variables are linear combinations of the original spectrum and are derived in decreasing order of importance [2]. Tholen did his PCA on the ECAS spectra [3] of 405 asteroids. The ECAS wavelength region is from 0.337 to 1.041μm.

The 1st principal component from Tholen's PCA contained 67.7% of the variance of the sample, while the 2nd principal component contained 26.8% of the variance. Tholen used a plot of the 1st and 2nd principal component to display the data since the first two components contained 94.5% of the variance. The reason why the first two components contained 94.5% of the variance is because asteroid spectra have just two major features in the ECAS wavelength region [4]. These features are an ultraviolet feature and an infrared feature.

Tholen also assigned a taxonomic class to each of the asteroids after doing a minimal tree cluster analysis on their spectra. Each of the asteroid classes have their own distinct regions on Tholen's plot of the 1st and 2nd principal component except for the Es, Ms, and Ps which are spectrally degenerate and must be separated by albedo. Later asteroid classification systems by Barucci et al [5] and Tedesco et al [6], which use both ECAS spectra and IRAS albedos, support most of Tholen's classifications. All asteroid classifications used in this paper will be from Tholen [7].

However very little work has been done on using PCA to display asteroid spectra for longer wavelength regions and seeing if the results are consistent with Tholen's classification system. In this preliminary study, PCA was done on asteroid spectra using a combination of ECAS and 52-color data. The 52-color asteroid survey of 119 asteroids which was done by Bell et al [7] is the first and only extensive spectral survey of asteroids in the 0.8 to 2.5μm wavelength region. 52-color data is useful for determining the presence or absence of the second pyroxene band near 1.9μm and the degree to which the spectra is reddened [8].

Before the PCA could be done, the 52-color spectrum of each asteroid was fitted to the overlapping region (0.853-1.041μm) of the asteroid's normalized ECAS spectrum so the resulting composite asteroid spectrum would be continuous. Due to the problems of correcting for atmospheric extinction, data from wavelengths near water bands at 1.4 and 1.9μm were not used. Also wavelengths near the edge of the detector's sensitivity (~2.5μm) were not used because of high uncertainties. PCA was done on the reflectance spectra at 41 wavelengths from 0.337 to 2.4130μm.

66 asteroids were deemed to have spectra of high-enough quality to do PCA on them. These asteroids [9] include 42 Ss (including 221 Eos), 3 Cs, 3 Gs, 1 B (2 Pallas), 3 Fs, 3 Ts, 1 V (4 Vesta), 1 R (349 Dembowska), 1 A (446 Aeternitas), 2 Es, 5 Ms, and 1 P (153 Hilda). As can be seen by these numbers, the type of asteroid is heavily biased toward Ss (63.6% of the sample) because most of the asteroids in the 52-color survey are Ss.

Figure 1 is a plot of the 1st and 2nd principal component from the resulting PCA and **Figure 2** is a plot of the 3rd and 4th component. Each asteroid is labeled with its taxonomic class except for five asteroids which are labeled with their number due to having obviously anomalous principal components when compared to other members of their taxonomic class. These asteroids with their taxonomic classes are 308 Polyxo (T), 354 Eleonora (S), 387 Aquitania (S), 980 Anacostia (SU), and 1036 Ganymed (S). Also 221 Eos is labeled with a K to see if its proposed designation as a K by Bell [10] is supported by its principal components.

The 1st component contains 78.5% of the variance and is dominated by the overall slope of the spectrum. The 2nd component contains 11.9% of the variance and appears to be related to the strength of the 1μm absorption feature. The 3rd component which contains 4.8% of the variance and the 4th component which contains 2.6% of the variance do not seem to have any simple correlations with any one feature in the original asteroid spectra, but do appear to be validly separating different asteroids according to different characteristics of their spectra. The remaining 37 components contain only 2.2% of the variance.

As seen by the general clustering of asteroids of the same taxonomic class in **Figures 1** and **2**, each asteroid class tends to have members which have similar principal components. If **Figures 1** and **2** could be combined into a single 4-dimensional plot, the resulting figure would look very much like a distorted view of Tholen's plot of his 1st and 2nd principal component [1] because each asteroid class would have its own region in this 4-dimensional space. Even though Tholen's classification system only uses a part of the spectral information that could be available from an asteroid, his asteroid classes tend to remain distinct from each other even after a PCA of asteroid spectra for a much larger wavelength region.

But some asteroids in this sample have principal components which render them distinct from other asteroids. These asteroids include 4 Vesta, 349 Dembowska, and 446 Aeternitas which are the lone representatives of their class in the sample. Of the five asteroids which have been identified as having anomalous principal components and are labeled by their numbers in **Figures 1** and **2**, four of them are Ss which is known to be the most heterogeneous of the asteroid classes [11]. These asteroids are 354 Eleonora which has a strong olivine

feature and no 2μm feature [12], 387 Aquitania and 980 Anacostia which both have a stronger 2μm than 1μm feature, and 1036 Ganymed which has a very strong 1μm and 2μm feature. Another S, 221 Eos, plots on the edge of the S-field near the C-types which lends support to its designation as a K. The fifth asteroid which is identified by its number is 308 Polyxo which has an overall slope which is vastly different from the other Ts, 114 Kassandra and 233 Asterope. It is interesting to note that Polyxo was observed by Jones et al [13] to have a 3μm hydrated silicate feature while the other two Ts do not. Polyxo has also been identified as anomalous by Zellner et al [6] in his three-parameter asteroid classification system. Other asteroids in the sample with anomalous components are still being identified.

As shown by this paper PCA is a very useful tool for displaying asteroid spectra for larger wavelength ranges. Within this small sample Tholen's asteroid classification system appears to work very well as a general divider for most asteroids. But it is obvious that some asteroids have spectra which are substantially different from other members of their taxonomic class. The proposed infrared extension of ECAS [14],which would have a wavelength coverage of 1 to 3.4μm, would easily be able to identify these anomalous asteroids.

References: [1] Tholen, D.J. (1984) *Asteroid Taxonomy From Cluster Analysis of Photometry*. Ph.D. Thesis, Univ. of Ariz., Tucson. [2] Chatfield, C. and Collins, A. J. (1980) *Introduction to Multivariate Analysis*. Chapman and Hall, NY. [3] Zellner, B. et al. (1985) *Icarus 61*, 355-416. [4] Tholen D. J. and Barucci, M. A. (1989) *Asteroids II*, Univ. of Arizona Press, 298-315. [5] Barucci, M. A. et al. (1987) *Icarus 72*, 304-324. [6] Tedesco et al. (1989) *Astronomical Journal 97*, 580-606. [7] Tholen D. J. (1989) *Asteroids II*, Univ. of Arizona Press, 1139-1150. [8] Bell, J. F. et al (1989) *Asteroids II*, Univ. of Arizona Press, 921-945. [9] Bell, J. F. et al (1988) *LPS XIX*, 57-58. [10] Bell, J. F. (1988) *Meteoritics 23*, 256-257. [11] Gaffey, M. J. (1990) *Eos 71*, 1432. [12] Gaffey, M. J. et al. (1989) *Asteroids II*, Univ. of Arizona Press, 98-127. [13] Jones, T. D. et al. (1990) *Icarus 88*, 172-192. [14] Bell, J. F. and Tholen, D. J. (1989).

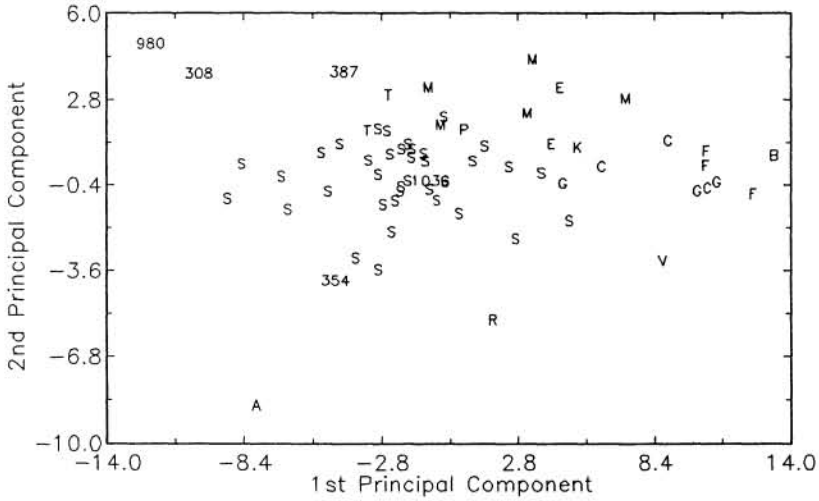
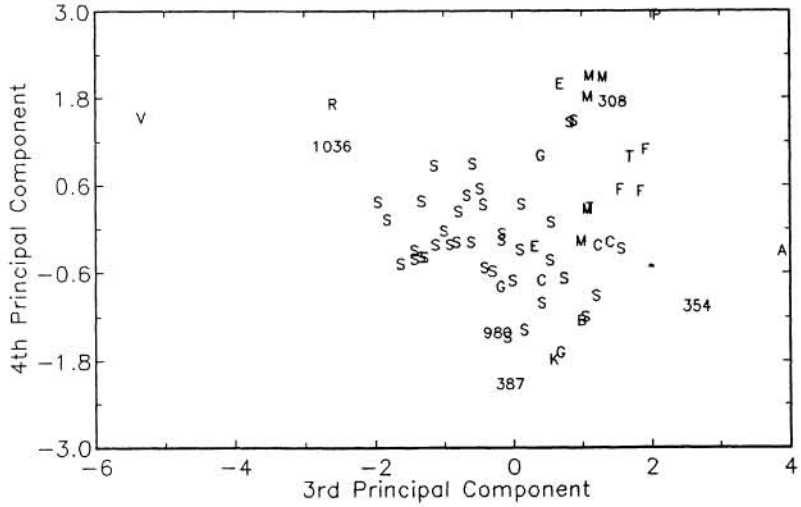


Figure 1: The 1st and 2nd principal component from the PCA of the combined ECAS and 52-color spectra of 66 asteroids. All asteroids are labeled with their Tholen class except for 221 Eos which is labeled as a K and five asteroids which are labeled with their numbers due to having anomalous components.



igure 2: The 3rd and 4th rincipal component from the PCA f the combined ECAS and 52-olor spectra of 66 asteroids